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DUST CLOUD MODELS: SENSITIVITY OF CALCULATED  
TRANSMITTANCES TO VARIATIONS IN INPUT PARAMETERS

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By

Melvin G. Heaps

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US Army Electronics Research and Development Command  
**Atmospheric Sciences Laboratory**

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20. ABSTRACT (cont)

choices. Several parameters from the different phases of dust cloud transmission problems have been varied within appropriate ranges. The more important parameters which can cause wide variations in the calculated transmittance are:

- The fraction of the actual crater mass remaining airborne, which affects the degree of obscuration
- Wind direction, which affects the position of the cloud with respect to the transmission line of sight
- The dust particle size distribution within the cloud, which affects the wavelength dependence of the obscuration

Comparisons with test data from the Dusty Infrared Test (DIRT) series show that current models are now able to correctly simulate many effects in dust cloud transmittance. Such comparisons have also shown a need for further improvements in the following areas:

- Initial (< 10 s) dust cloud development, models generally show different transmittance drop-offs in this time frame than the data would indicate for explosions on the transmission line of sight
- Inclusion of large turbulence eddies in dust cloud growth and movement (transmittance data often show "holes" appearing in clouds)
- A better determination of the ground-hugging, nonbuoyant dust skirt (Most transmission measurements occur within 3 m of the surface.)
- Inclusion of variation of meteorological parameters for long persisting (> 1 min) dust clouds

## CONTENTS

LIST OF TABLES AND FIGURES.....	5
1. INTRODUCTION.....	7
2. SELECTION OF TEST DATA AND MODEL PARAMETERS.....	7
3. COMPARISON OF MODELED VARIATION WITH TEST DATA.....	12
4. DISCUSSION AND CONCLUSIONS.....	27
REFERENCES.....	31

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## LIST OF TABLES AND FIGURES

### TABLE

1. MODELING PARAMETERS.....	8
2. VARIABLE PARAMETERS.....	13
3. INPUT DATA FOR TEST CASES.....	15

### Figure

1. DIRT-II Trial B-7 Transmissometer Data.....	9
2. DIRT-II Trial A-11 Transmissometer Data.....	9
3. DIRT-II Trial B-7 Crater Scaling (0.55 Micrometer).....	16
4. DIRT-II Trial B-7 Crater Scaling (10.37 Micrometers).....	16
5. DIRT-II Trial A-11 Crater Scaling (0.55 Micrometer).....	17
6. DIRT-II Trial A-11 Crater Scaling (10.37 Micrometers).....	17
7. DIRT-II Trial B-7 Hydro-yield Factor (0.55 Micrometer).....	19
8. DIRT-II Trial B-7 Hydro-yield Factor (10.37 Micrometers).....	19
9. DIRT-II Trial A-11 Hydro-yield Factor (0.55 Micrometer).....	20
10. DIRT-II Trial A-11 Hydro-yield Factor (10.37 Micrometers).....	20
11. DIRT-II Trial B-7 Pasquill Category (0.55 Micrometer).....	21
12. DIRT-II Trial B-7 Pasquill Category (10.37 Micrometers).....	21
13. DIRT-II Trial A-11 Pasquill Category (0.55 Micrometer).....	22
14. DIRT-II Trial A-11 Pasquill Category (10.37 Micrometers).....	22
15. DIRT-II Trial B-7 Winds (0.55 Micrometer).....	23
16. DIRT-II Trial B-7 Winds (10.37 Micrometers).....	23
17. DIRT-II Trial A-11 Winds (0.55 Micrometer).....	24
18. DIRT-II Trial A-11 Winds (10.37 Micrometers).....	24
19. DIRT-II Trial B-7 Wind Direction (0.55 Micrometer).....	25
20. DIRT-II Trial B-7 Wind Direction (10.37 Micrometers).....	25
21. DIRT-II Trial A-11 Wind Direction (0.55 Micrometer).....	26

Figure

22. DIRT-II Trial A-11 wind Direction (10.37 Micrometers).....	26
23. DIRT-II Trial B-7 Soil Distribution (0.55 Micrometer).....	29
24. DIRT-II Trial B-7 Soil Distribution (10.37 Micrometers).....	29
25. DIRT-II Trial A-11 Soil Distribution (0.55 Micrometer).....	30
26. DIRT-II Trial A-11 Soil Distribution (10.37 Micrometers).....	30

## 1. INTRODUCTION

The modeling of artillery-produced and high-explosive-produced dust clouds and the resultant transmission of visible and infrared radiation through these clouds can be divided into three phases. The first phase deals with cratering and initial cloud properties and determines how much material is put into the cloud. The second phase deals with transport and diffusion of the resulting dust cloud and is important in determining the density of the dust cloud and its position with respect to the transmission line of sight. The third phase deals with the transmission of visible and infrared radiation through the dust aerosol and depends upon the particle size distribution and the composition of the material in the cloud.

In modeling the transmission through dust clouds, certain inputs to the models are desired, but these inputs may not always correspond to directly measured (or measurable) quantities. Table 1 shows some parameters which are commonly used in modeling, either as inputs or internally carried values, along with a comment about what quantity is actually measured. Uncertainties arise in determining a best value to be used because either the measurement itself yields a large range of possible values and an interpolation is then required, or the quantity cannot be readily measured and an "educated guess" must be made.

The effect on the resultant transmission of the range of values of the model input parameters shall be studied here. The standard for comparison shall be the measured transmission through artillery-produced dust clouds. The desired model output is the calculated transmittance at selected visible and infrared wavelengths. Selected inputs from each of the three phases of the dust cloud transmission problem shall be varied to determine their effects on and importance to the resultant transmittance.

## 2. SELECTION OF TEST DATA AND MODEL PARAMETERS

The test data shall be taken from the Dusty Infrared Test - II (DIRT-II) Program<sup>1</sup> conducted at White Sands Missile Range, NM, in July 1979. The test series consisted of single explosions from tube-delivered (live fire) artillery rounds, statically detonated artillery shells, and statically detonated bare charges. From the many cases available, this report shall use selected cases of 105-mm and 155-mm shells. The quantity used for comparison shall be the transmittance through the artillery-produced dust clouds.<sup>2</sup> Figures 1 and 2 are examples of the transmittance at visible and infrared wavelengths versus time for statically detonated 105-mm and 155-mm shells.

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<sup>1</sup>B. W. Kennedy, Editor, 1980, Dusty Infrared Test - II (DIRT-II) Program, ASL-TR-0058, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>2</sup>J. A. Curcio, K. M. Haught, and M. A. Waytko, 1980, "Transmittance Measurement at DIRT-II," Chapter 6 in Dusty Infrared Test - II (DIRT-II) Program, ASL-TR-0058, (B. W. Kennedy, Editor), Atmospheric Sciences Laboratory, White Sands Missile Range, NM

TABLE 1. MODELING PARAMETERS

Need to Know	What is Measured
Crater volume	Apparent crater diameter(s) and depth
Mass lofted - Cloud and dust skirt	No direct measurements (debris measurements - indirect)
Energy partitioned (to initial cloud)	No direct measurements (cloud rise rates - indirect)
Pasquill category	Estimated from solar insolation, cloud cover, and windspeed
Windspeed and wind direction	Windspeed and wind direction (often at different location)
Particle size distribution (in the cloud)	Particle size groups (sand/silt/clay) Sieve and hydrometer sizing (soil) Impactor sampling (cloud) Real-time in-situ sampling (cloud)

The dust cloud transmission model used is one being developed under the auspices of the US Army Atmospheric Sciences Laboratory.<sup>3</sup> \* While this specific model can neither (and need not) represent all the various inputs required by different models nor identically parallel all algorithms and methods of solution used, it is a reasonable representation of the state of the art in dust cloud obscuration modeling.<sup>4</sup> \* The main objective is to

<sup>3</sup>J. H. Thompson, 1979, Models for Munitions Dust Clouds, ASL-CR-79-0005-2, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>4</sup>J. H. Thompson, 1980, ASL-DUST: A Tactical Battlefield Dust Cloud and Propagation Code, Volume 1 - Model Formulations, ASL-CR-80-0143-1, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>5</sup>J. H. Thompson, 1980, ASL-DUST: A Tactical Battlefield Dust Cloud and Propagation Code, Volume 2 - User's Manual, ASL-CR-80-0143-2, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>6</sup>M. G. Heaps, 1980, "Evaluation of Cratering Parameter on Transmission Through Artillery Produced Dust Clouds (U)," Proceedings of the Smoke/Obscurants Symposium IV, Volume 2, DRCPM-SMK-T-001-80, CONFIDENTIAL, Harry Diamond Laboratories, Adelphi, MD

<sup>7</sup>M. G. Heaps, 1980, "The Effect of Meteorological Parameters on Artillery Produced Dust Cloud Size, Growth, and Transport (U)," Proceedings of the Smoke/Obscurants Symposium IV, Volume 2, DRCPM-SMK-T-001-80, CONFIDENTIAL, Harry Diamond Laboratories, Adelphi, MD

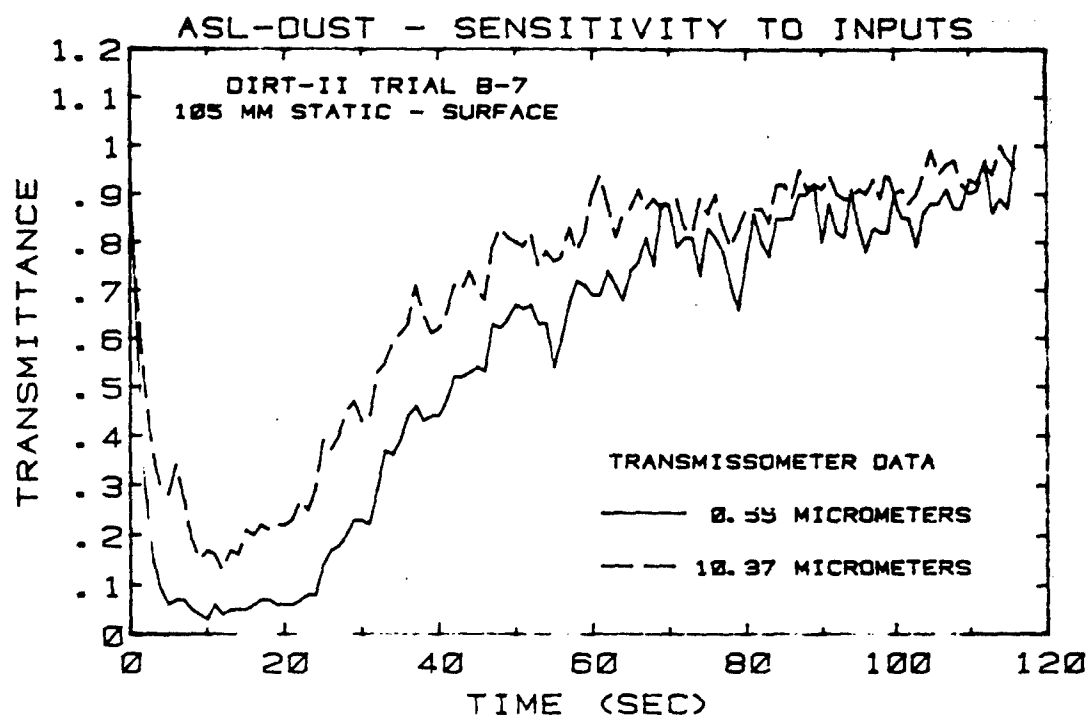


FIGURE 1. DIRT II TRIAL B-7 TRANSMISSOMETER DATA  
105 MM static round at .55 and 10.37 micrometers.

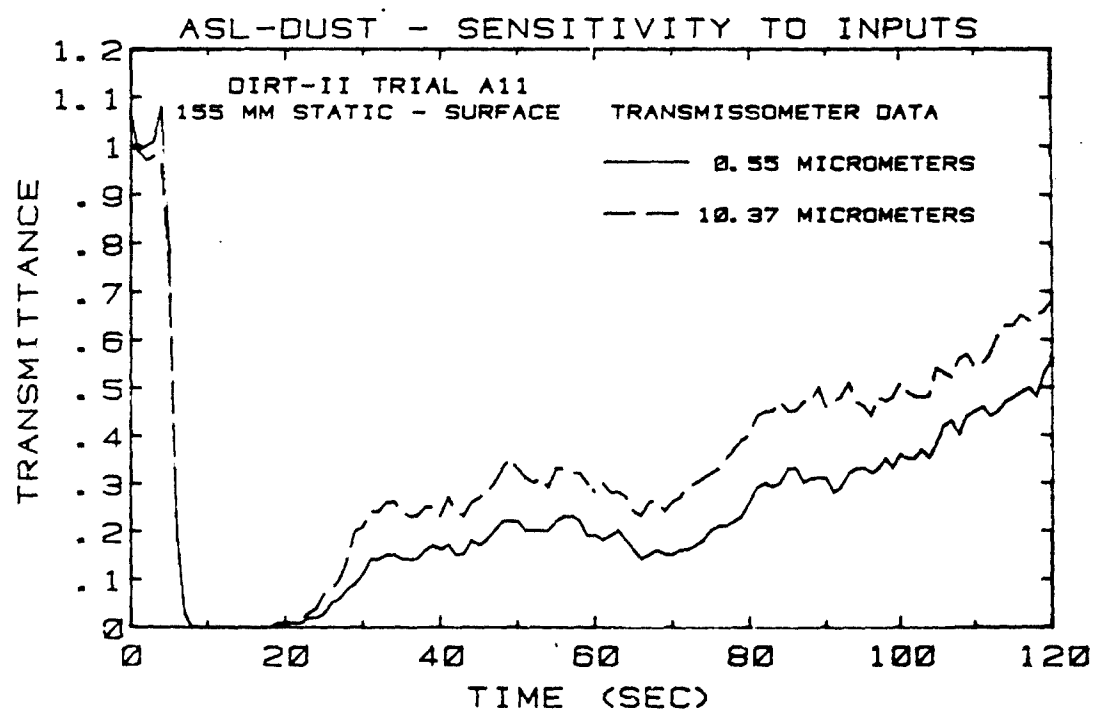


FIGURE 2. DIRT II TRIAL A11 TRANSMISSOMETER DATA  
155 MM static round at .55 and 10.37 micrometers.

select a representative subset of potential input parameters and determine the sensitivity of the modeled transmittance to their variation.

The first phase of dust cloud modeling deals with cratering and the properties of the initial (that is, essentially instantaneous) cloud. Several scaling laws have been developed which relate the apparent crater volume to the explosive charge type and positioning. Typical variations of actual crater volumes about the mean predicted crater volume are +30 percent, that is, approximately a factor of two variation between the smaller and large crater volumes for a given soil type.

Next one must determine how much of the actual crater volume becomes airborne in the dust cloud, as opposed to being distributed as crater ejecta about the rim. Current estimates are that 25 percent of the apparent crater volume actually enters the cloud, but there is certainly another factor of two variation inherent here. The basic quantity which needs to be specified is how much material is actually in the cloud, and this quantity is a function of the apparent crater volume, the fraction which enters the cloud, and the soil type. The basic parameter used here shall be called the lofted crater mass ( $L_{cm}$ ), which shall be used as a multiplicative factor relating the amount of soil lofted to the explosive charge weight,

$$M(\text{kg}) = 0.25 \rho L_{cm} W^{1.111}, \quad (1)$$

where  $M$  is the amount lofted (kilograms),  $\rho$  is the soil density (kilograms per cubic meter), and  $W$  is the explosive charge (in pounds of TNT).  $L_{cm}$  has a median value of 0.03 for artillery shells, but can vary between 0.01 and 0.075.

The initial (that is, "instantaneous") size of an artillery dust cloud is usually scaled to an equivalent radius, determined from shock wave theory, which is approximately the radius of a sphere whose size is determined by the amount of explosive energy available to do work expanding the cloud against atmospheric pressure. For artillery shells, this equivalent radius is on the order of 2 to 3 m. The initial cloud is often not spherical, particularly for cased and shaped charges, and thus an ellipsoid may be chosen for the initial cloud shape. However, the subsequent growth and diffusion of the cloud begins to obscure the effects of any initial shape within a few seconds. Thus, the effects of incorrectly scaling the initial cloud shape are felt to be less important than the possible variation in the parameter governing the  $L_{cm}$ , and these effects would be most noticeable only in the early period of dust cloud growth.

Visual examination of high-explosive and artillery-produced dust clouds shows that a nonbuoyant base cloud or dust skirt accompanies the formation of the buoyantly rising main dust cloud. For modeling purposes this initial base cloud is given three times the horizontal dimensions and the same vertical extent as the initial main dust cloud. The airborne mass of the base cloud or dust skirt is taken to be 10 percent that of the main cloud. The subsequent

diffusion and transport of the base cloud or dust skirt are taken to be independent of the main cloud, though governed by the same physics and meteorology. The base cloud is taken to be "cold" and therefore has no subsequent vertical rise other than by diffusion. Because most lines of sight for electro-optical sensors are near the ground, the base cloud or dust skirt plays a large role in the resultant dust cloud obscuration effects. Because the base cloud is initially scaled to the main cloud, the potential errors and variation of parameters inherent in the formulation of the main cloud are also present for the base cloud.

Therefore, the variations possible in the first phase of dust cloud modeling, which governs cratering and initial cloud properties, center primarily in the areas of determining the amount of actual material in the cloud, defining the shapes of the initial base and main cloud, and determining the airborne mass of the base cloud or dust skirt. The largest uncertainty is in the parameter  $L_{cm}$ , which scales the amount of material in the dust cloud as a function of soil type. This parameter shall be varied to represent the largest range of uncertainties present in the first phase.

The second phase of dust cloud modeling deals with transport and diffusion, is influenced heavily by meteorological parameters, and determines the distribution and position of the cloud with respect to the optical line of sight. Four parameters influence this phase of the modeling problem. The first, the energy partitioned  $E_p$ , represents that fraction of energy of the initial explosion which is available for the rise and expansion of the main cloud. Current estimates place the value of  $E_p$  at 25 to 30 percent, but there is certainly a factor of two variability, depending on explosive charge type, placement, and soil characteristics.

The next three parameters express the dependence of this phase of dust cloud modeling on meteorological quantities. The Pasquill category represents a quantification of atmospheric stability in six discrete steps from very unstable to very stable (the conventional Pasquill categories A through F). This parameter is estimated from meteorological observations of windspeed, cloud cover, and solar insolation. Its use within the model is to select sets of values to be used in the diffusion of the base cloud and of the main cloud after its buoyant rise and expansion phase. The final two parameters are the windspeed and wind direction. These can be measured directly (though usually not precisely where the cloud is at any given moment) and used as inputs to the dust cloud model. In practice these parameters are usually held constant or averaged over periods of 1 or 2 minutes, which are the normal lifetimes of single artillery dust clouds.

The third phase of dust cloud modeling deals with the transmission of radiation through the dust cloud and depends primarily upon the composition and particle size distribution of the cloud. The composition of the soil and its optical properties (that is, wavelength dependent indices of refraction) can be determined to some degree from soil samples. In addition, the current model allows that 30 percent of the explosive charge by weight produce micrometer sized carbon particles which are evenly distributed throughout the cloud. An actual determination of the cloud's particle size distribution has proved to be a difficult problem. Attempts have been made to measure the

particle size distribution "in-situ" at various tests,<sup>1</sup> but results are not yet felt to be reliable or representative. Soil samples and soil sieving techniques can give a reasonable representation of the gross particle size distribution of the soil in its natural state, but whether the explosion itself preserves this "natural size" distribution is unclear. To be able to adequately model a wide range of soil types, the current model uses an easily and commonly measured parameter which is the percentage composition of the soil as sand, silt, and clay. Sand represents particles of size 50 $\mu$ m to 2000 $\mu$ m, silt represents particles of size 2 $\mu$ m to 50 $\mu$ m, and clay represents particles of size < 2 $\mu$ m. Representative particle size distributions and indices of refraction are assigned to each group. The composition of the initial cloud is then related directly to the soil composition, with an added small component of carbon. Subsequent settling of the large size particles as time progresses will then cause a change in the relative composition of the cloud and also in its optical properties.

Table 2 lists the parameters to be varied in subsequent simulations of test data. Where it is applicable, the average value of the parameter and its range are also given.

### 3. COMPARISON OF MODELED VARIATION WITH TEST DATA

The test data shown in figures 1 and 2 illustrate two points which should be noted. First, the rather jagged or stochastic nature of the actual transmission data is due to turbulence and the many small inhomogeneities actually present within the cloud; often large eddies are present which give brief "transmission holes" in the dust cloud. It is beyond the state of current computer codes to model anything but a continuum approach to the effects of turbulence and therefore simulated transmission data appear as smooth curves. Second, the actual data often show larger transmittances at infrared than at visible wavelengths, as figures 1 and 2 demonstrate. This particular feature, while frequently observed, is by no means consistently present even within a test series.

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<sup>1</sup>B. W. Kennedy, Editor, 1980, Dusty Infrared Test - II (DIRT-II) Program, ASL-TR-0058, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>2</sup>G. Fernandez and R. G. Pinnick, 1980, "Particle Size Measurements," Chapter 8 in Dusty Infrared Test - II (DIRT II) Program, ASL-TR-0058, (B. W. Kennedy, Editor), Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>3</sup>J. Mason, 1980, "Site Characterization for the MBCE/DIRT-II Battlefield Environment Tests," Chapter 9 in Dusty Infrared Test - II (DIRT-II) Program, ASL-TR-0058, (B. W. Kennedy, Editor), Atmospheric Sciences Laboratory, White Sands Missile Range, NM

<sup>4</sup>J. D. Lindberg, Compiler, 1979, Measured Effects of Battlefield Dust and Smoke on Visible, Infrared, and Millimeter Wavelength Propagation: A Preliminary Report on Dusty Infrared Test - I (DIRT-I), ASL-TR-0021, Atmospheric Sciences Laboratory, White Sands Missile Range, NM

TABLE 2. VARIABLE PARAMETERS

Parameter	Value Used
Crater mass lofted ( $L_{cm}$ ) (relates the amount of material lofted to the size of the explosive charge; a function of charge type, placement, and soil type).	$L_{cm} = 0.06 - 0.075$ range: 0.01 to 0.075
Energy partitioned ( $E_p$ ) (a measure of the fraction of explosive energy available for rise and expansion of the main cloud; a function of charge type, placement, and soil type).	$E_p = 0.25$ range: 0.125 to 0.5
Pasquill category (a quantification of atmospheric stability affecting the diffusion of the cloud).	A - F (value estimated from meteorological observations) range: $\pm$ one category
Windspeed	Measured (average) value range: $\pm 0.5$ to 1 m/s
Wind direction	Measured (average) value range: $\pm 10^\circ$
Particle size distribution (present distribution for different soil components are used).	Based on percentage composition of sand, silt, and clay in the soil. range: $\pm 10$ to 20 percent of measured values

Two test cases, already shown in figures 1 and 2, have been chosen to illustrate the variation one might expect between actual and simulated transmission data when the input quantities to the model are changed. The first case is for a 105-mm shell detonated a reasonable distance from the line of sight. The detonation cloud was carried across the line of sight at a somewhat oblique angle. The second case is for a larger 155-mm shell detonated closer to the line of sight. The detonation cloud was carried almost parallel to, but slightly away from, the line of sight. Table 3 gives the basic input data for each case.

Figures 3 through 6 show the simulated transmittances for 105-mm (trial B-7) and 155-mm (trial A-11) explosions. The visible ( $0.55\mu\text{m}$ ) and infrared ( $10.37\mu\text{m}$ ) transmittances are shown separately. The parameter which has been varied is the  $L_{\text{cm}}$ . The larger values were taken from the averaged crater sizes for all statically detonated 105-mm and 155-mm shells, respectively. The smaller values of  $L_{\text{cm}}$  were chosen as a lower limit for the types of desert soils present in the DIRT series. As might be expected, the measured  $L_{\text{cm}}$  for the respective sets of trials give the better representation of the measured transmittances.

Figures 3 and 4 show that the early time modeled transmittances do not drop off as rapidly as the test data would indicate. Examination of numerous cases of similarly placed charges (that is, more than 10 m from the line of sight, such that the cloud is not initially in the line of sight) shows a similar trend. The indication is that the size and expansion of the base cloud or dust skirt are not correctly modeled for the first few seconds of the dust cloud's lifetime. In contrast, for dust clouds which are very close to the line of sight, similar to those plotted in figures 5 and 6 and other cases which were examined, the modeled transmittances dropped off more rapidly than the measured ones. The indication here is that the transmissometer may not have responded accurately during the initial seconds of rapid transmission decrease. Thus, comparisons between simulated and measured data for initial times less than approximately 10 seconds may not always be valid.

Figures 3 through 6 show that the larger values for the  $L_{\text{cm}}$  factor provide the better simulation of the transmission data. Because the main cloud eventually rises several tens of meters above the surface, while the base cloud stays within several meters of the surface, the main cloud moves out ahead of the base cloud or dust skirt due to the normal wind shears present in the atmospheric boundary layer. Thus for trials such as B-7, shown in figures 3 and 4, where the cloud is blown across the line of sight, the obscuration at later times is due primarily to the base cloud; the main cloud is above and beyond the line of sight at these later times. In trial A-11 (figures 5 and 6) the bulk of the obscuration at earlier times is caused by the main cloud because the track of the two clouds so closely parallels the line of sight. The main cloud, while above the line of sight, is still expanding down into it; after about 40 seconds the base cloud also begins to diffuse up into the line of sight and causes the majority of the obscuration after this time. The decline in the rate of improving transmittance seen in figures 5 and 6 after 60 seconds is due to the continued diffusion of base cloud up into the line of sight, while the larger particles ( $>80\mu\text{m}$ ) of the main cloud are beginning to settle down into the line of sight.

TABLE 3. INPUT DATA FOR TEST CASES

Parameters	B-7 (105 mm)	A-11 (155 mm)
Distance from line of sight	19.5 m east	10.4 m west
Height of line of sight above detonation point	7.5 m	7.5 m
Estimated Pasquill category	B	B
Windspeed	2.4 m/s	3.7 m/s
Wind direction	165°	36°
Angle of wind wrt line of sight	41° (across)	10° (away)
Soil type	Silty clay with varying amounts of sand; composition taken as 25 percent sand, 50 percent silt, 25 percent clay	
Indices of refraction	$\lambda = 0.55\mu\text{m}$	$\lambda = 10.37\mu\text{m}$
Clay	1.52 - 0.00071	2.16 - 0.1491
Silt	1.55 - 0.00011	2.35 - 0.03151
Sand	1.55 - 0.00011	2.35 - 0.03151
Carbon	1.75 - 0.441	2.22 - 0.7261
Type of explosive charge	Statically detonated artillery shell placed with nose tip on the ground at an angle of about 11° with the surface	

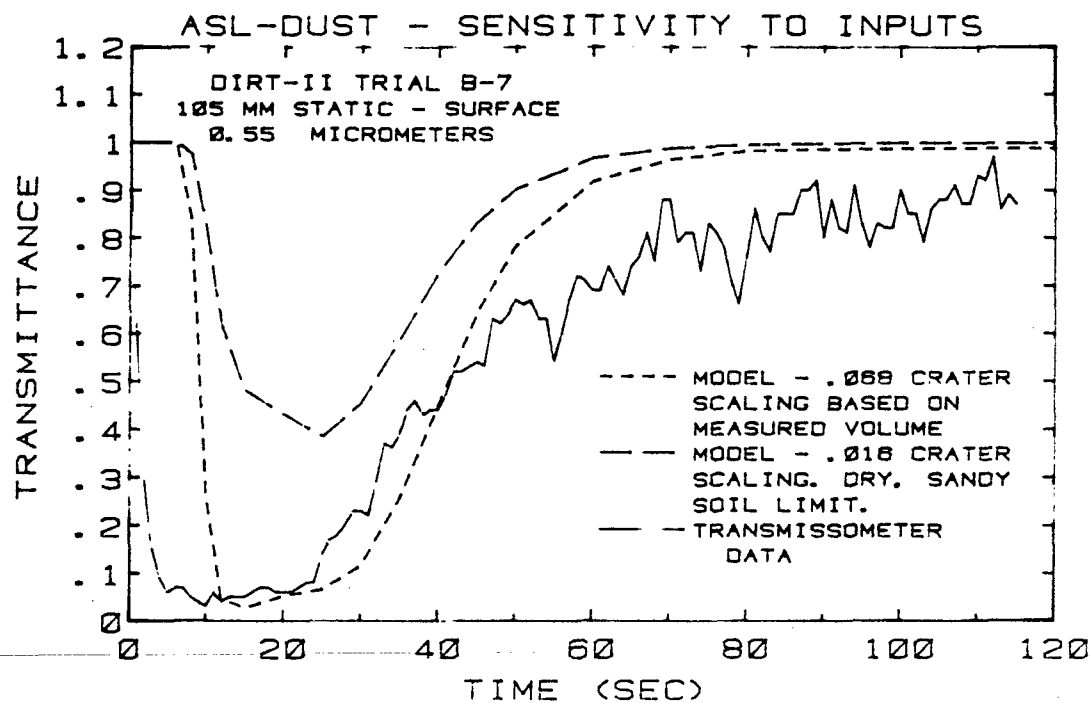


FIGURE 3. DIRT II TRIAL B-7 CRATER SCALING.  
Variation in crater scaling factor.

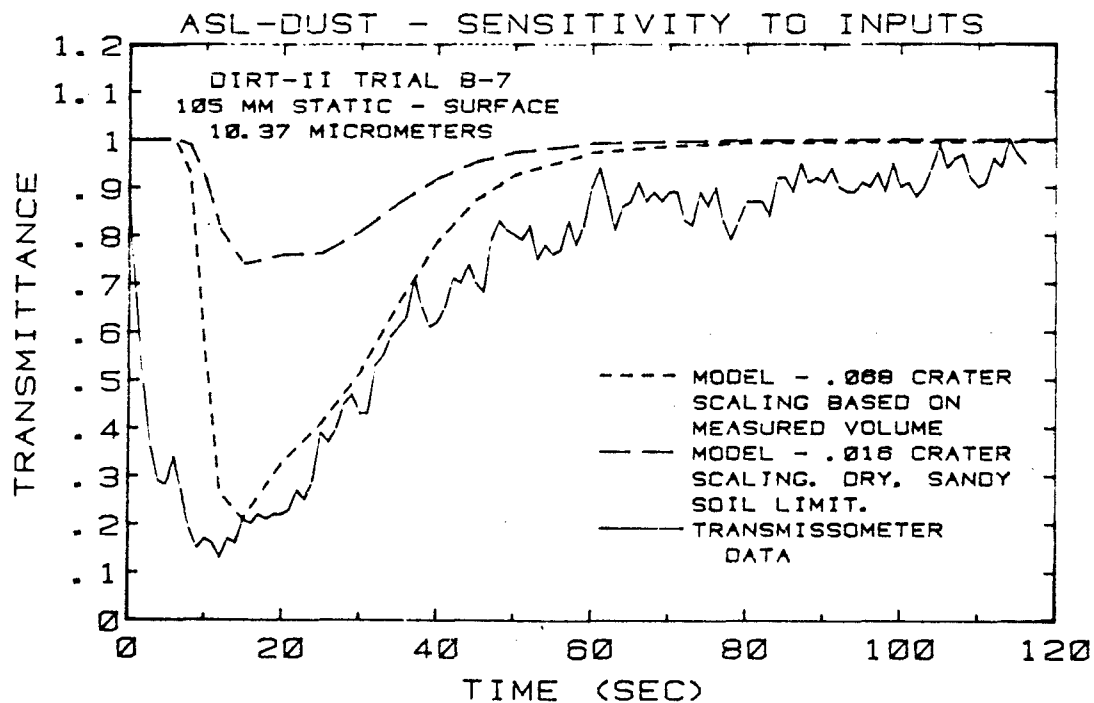


FIGURE 4. DIRT II TRIAL B-7 CRATER SCALING.  
Variation in crater scaling factor.

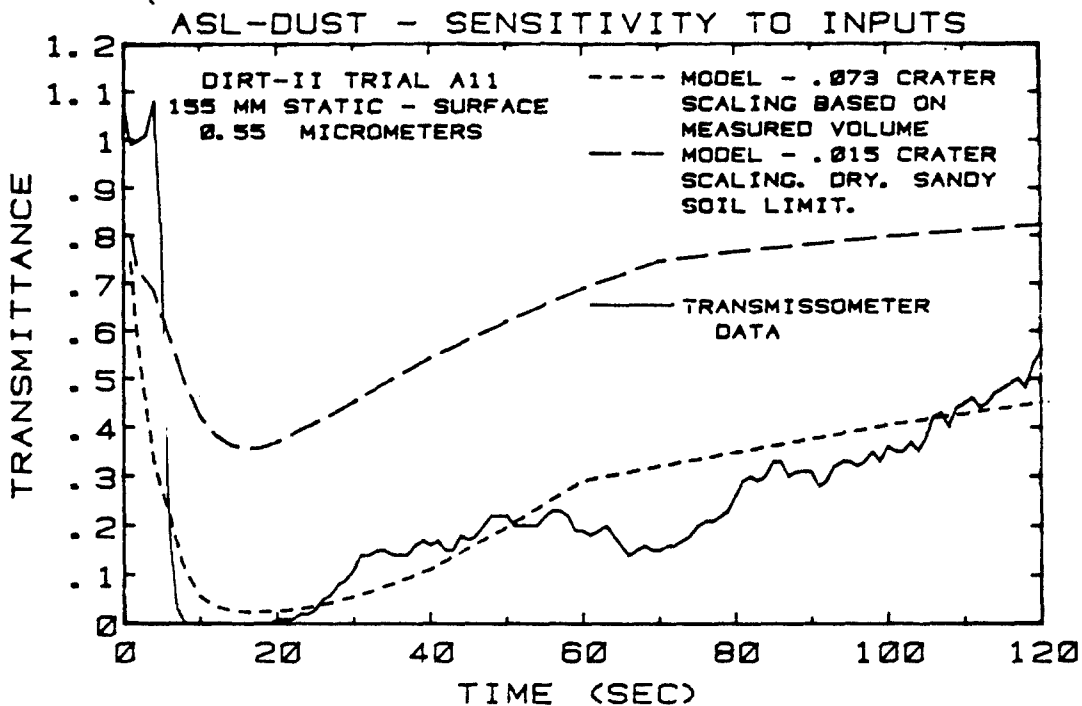


FIGURE 5. DIRT II TRIAL A11 CRATER SCALING.  
Variation in crater scaling factor.

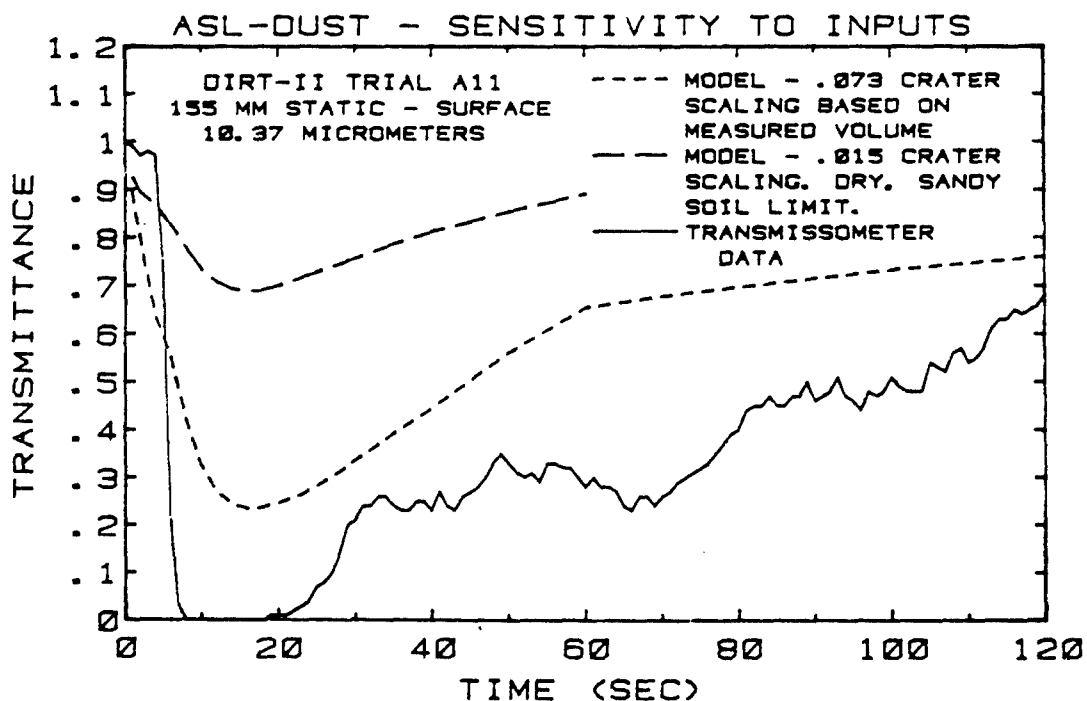


FIGURE 6. DIRT II TRIAL A11 CRATER SCALING.  
Variation in crater scaling factor.

Figures 7 through 10 show the effect of varying the energy partitioned fraction,  $E_p$ . The figures show that as the  $E_p$  fraction increases the simulated transmittances are decreased during the main portion of the recovery phase. This increase-decrease phenomenon is due to two reasons: (1) The initial size of the main cloud, and hence the base cloud or dust skirt, is scaled to the amount of energy "available" to the cloud from the explosion. Thus for larger values of  $E_p$  the initial base and main clouds are larger and extend into the line of sight to a greater extent. (2) Although the main cloud is rising at a somewhat more rapid rate, it is also expanding at a more rapid rate such that the amount of material in the line of sight due to the main cloud is slightly increasing. Only at later times, after the cloud has moved through and away from the line of sight, does the effect of a larger, more diffuse cloud finally dominate; and the larger values of  $E_p$  begin to show a slightly larger transmittance.

Figures 11 through 14 show the effect of varying the Pasquill category. This parameter is varied in a step-like manner, and the range of simulated transmittances shows the importance of making an initially reasonable estimate. The Pasquill parameter primarily controls the diffusion of the base cloud and, after the rise and expansion phase, of the main cloud. The effect of changing the Pasquill category to more unstable conditions is to increase the rate of diffusion of the cloud which, for the cases illustrated, causes more material to be diffused into the line of sight. Thus changing the Pasquill category from B+A decreases the simulated transmittance. Figures 12 and 14 indicate that for infrared transmission a change in the Pasquill category to a more unstable value at later times gives a somewhat better fit to the data, which may indicate that the transport and diffusion of the larger particles in the late-time cloud have been initially underestimated.

Figures 15 through 18 show the effect of varying the windspeed. The general effects are small, particularly when the cloud tends to parallel the line of sight, as in figures 17 and 18. When the wind is more of a crosswind to the line of sight, the entire profiles just slide over a few seconds in time, which is what one would expect. Of course the two profiles are not absolutely identical due to small differences in the respective speeds of the main and base clouds.

Figures 19 through 22 illustrate the effects of changing the wind direction. The differences are larger here for slight changes in wind direction than they were for the previous changes in windspeed. For trial A-11 (figures 21 and 22), where the cloud path nearly parallels the line of sight, a slight change in direction causes a very large change in the simulated transmittances. In this instance the simulated cloud path is only  $5^\circ$  from the line of sight; for the earlier part of the infrared transmission profile in figure 22, this altered wind direction gives a better fit to the data, though this does not seem to be the case for the visible transmission profile in figure 21. Again this may be an indication that the transport and diffusion of the various particle size groups are not being optimally modeled. In reality, the wind direction and windspeed do vary slightly on time scales of a few seconds; these factors are two causes of the stochastic nature of the actual transmission data.

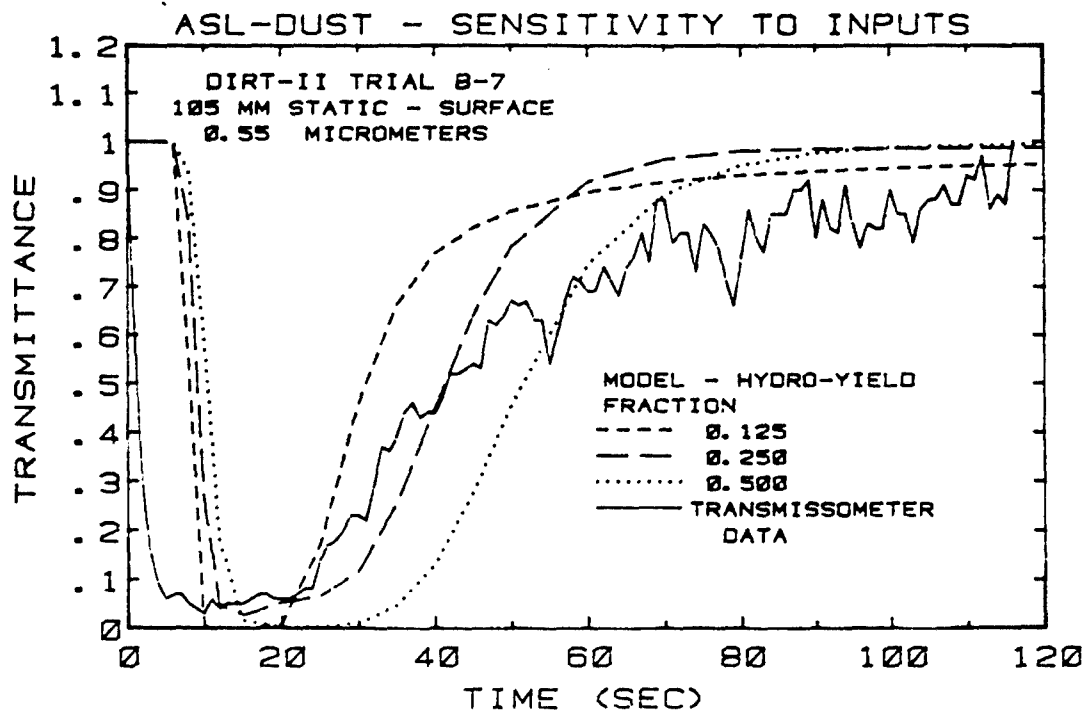


FIGURE 7. DIRT II TRIAL B-7 HYDRO-YIELD FACTOR.  
Variation in hydro-dynamic energy fraction.

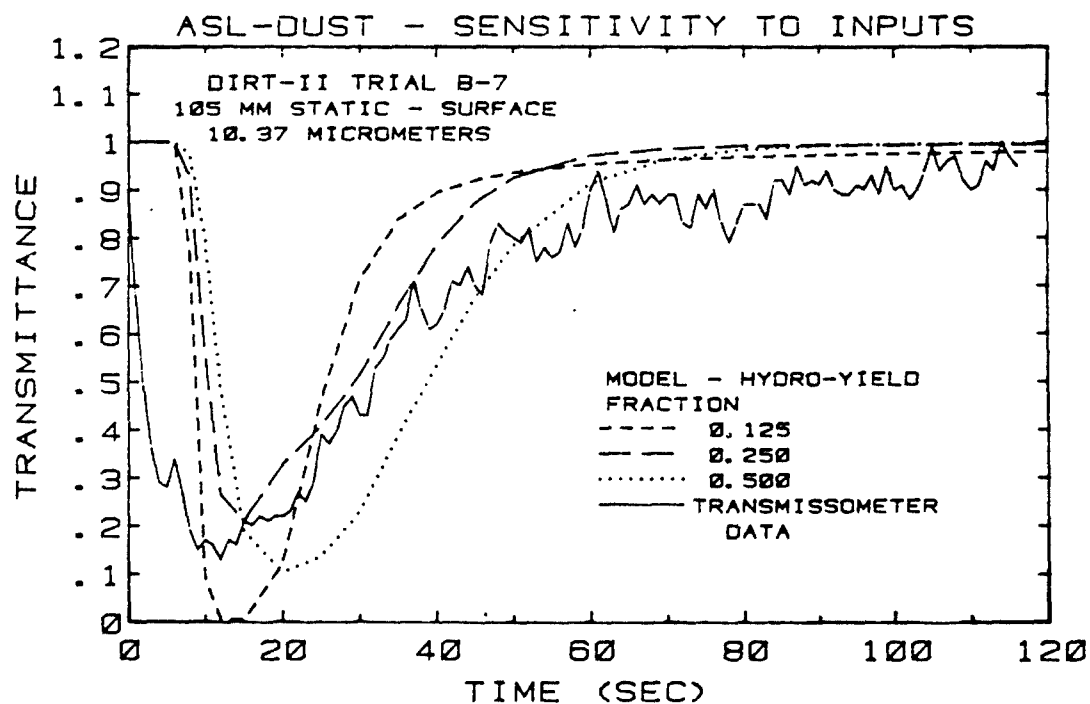


FIGURE 8. DIRT II TRIAL B-7 HYDRO-YIELD FACTOR.  
Variation in hydro-dynamic energy fraction.

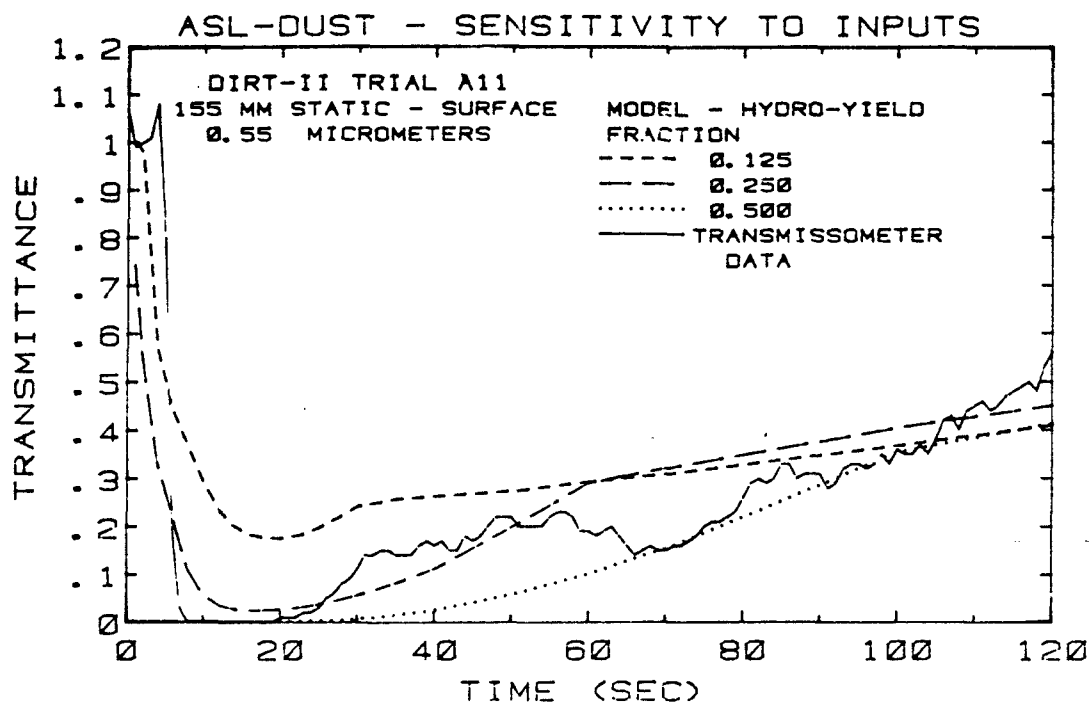


FIGURE 9. DIRT II TRIAL A11 HYDRO-YIELD FACTOR.  
Variation in hydro-dynamic energy fraction.

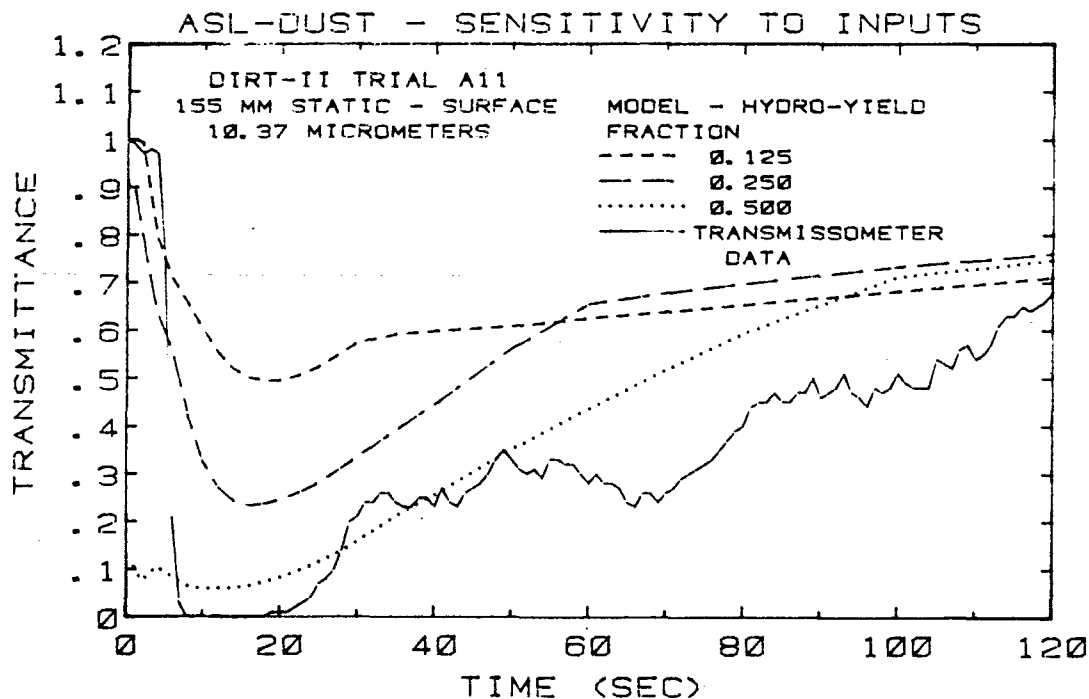


FIGURE 10. DIRT II TRIAL A11 HYDRO-YIELD FACTOR.  
Variation in hydro-dynamic energy fraction.

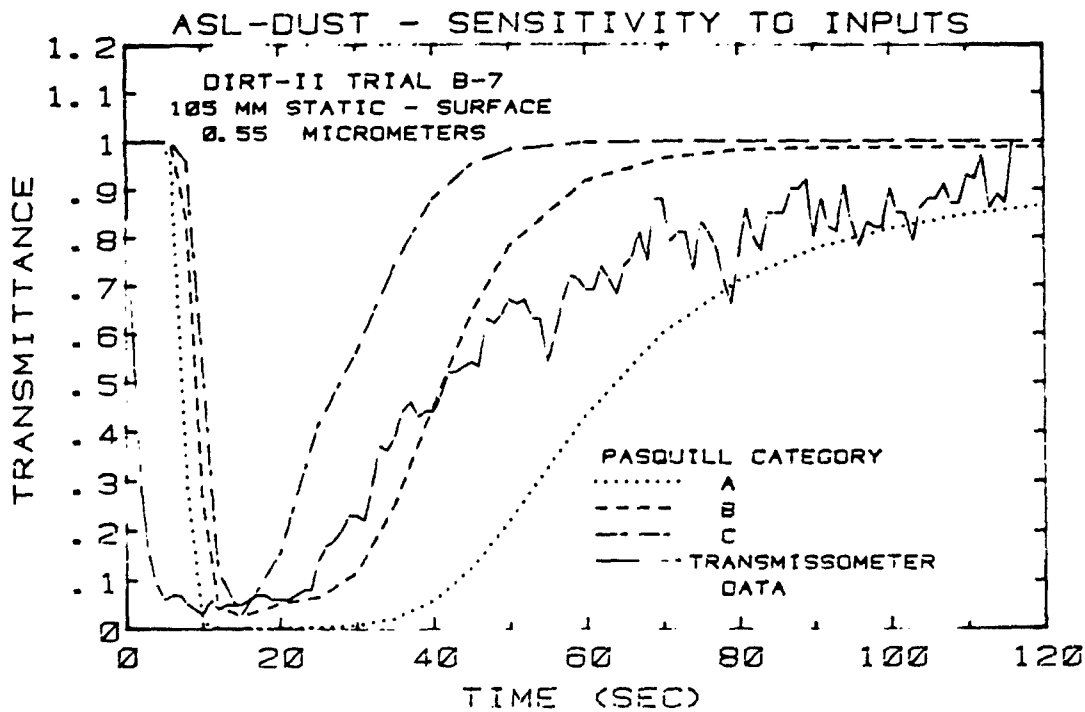


FIGURE 11. DIRT II TRIAL B-7 PASQUILL CATEGORY.  
Variation over Pasquill Stability Categories.

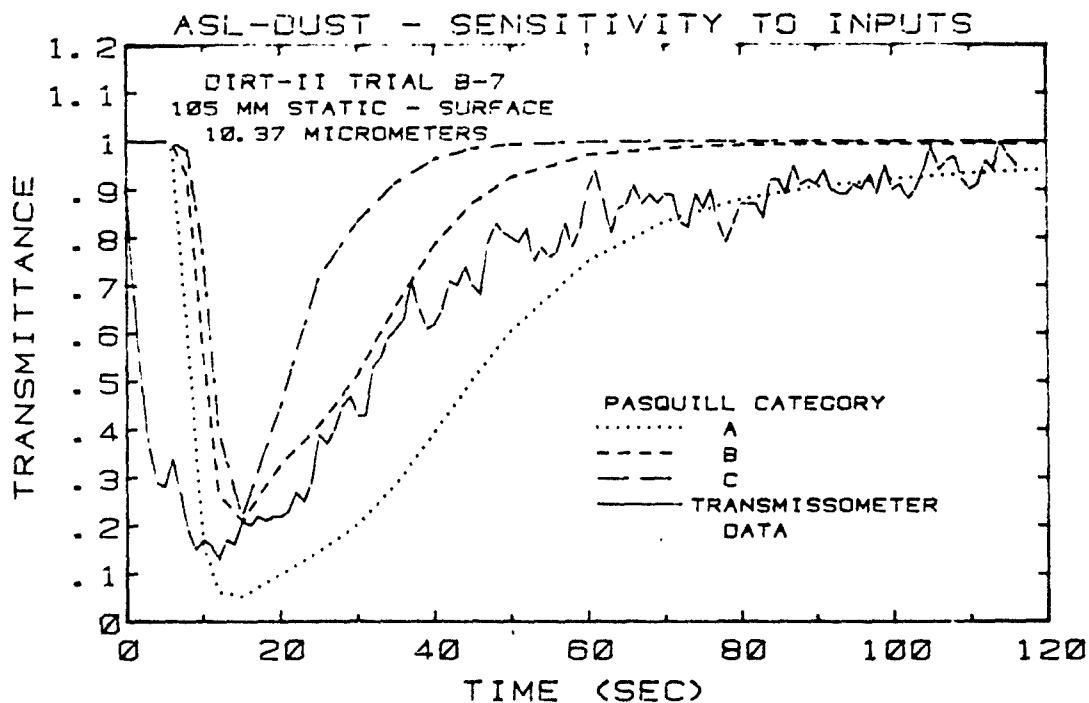


FIGURE 12. DIRT II TRIAL B-7 PASQUILL CATEGORY.  
Variation over Pasquill Stability Categories.

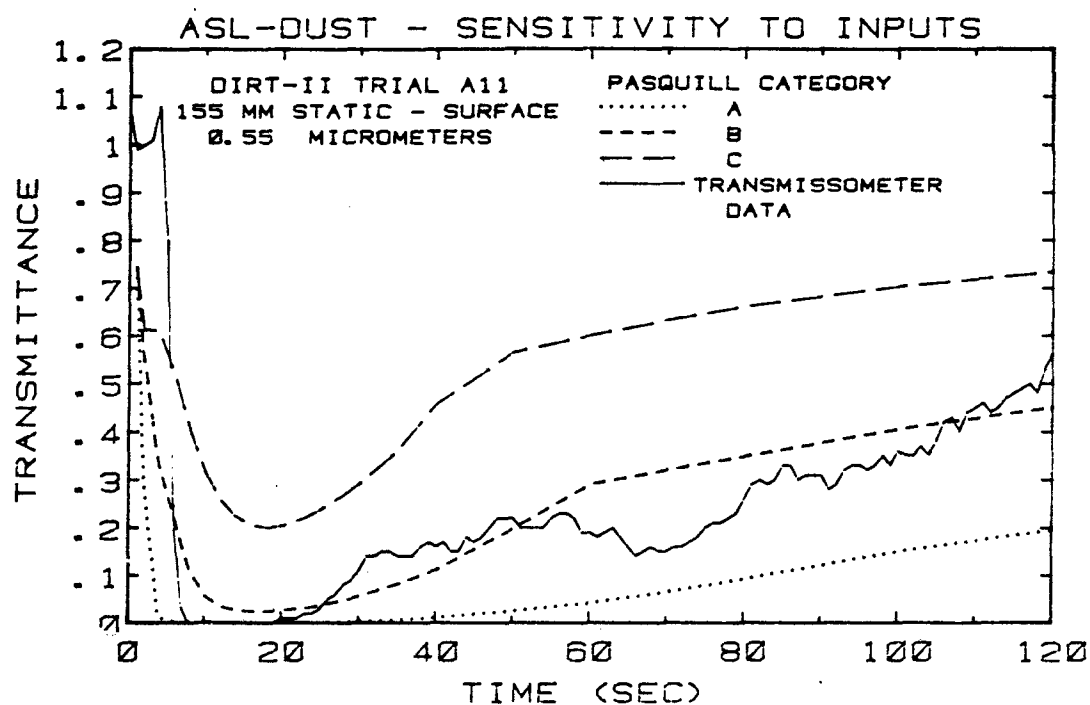


FIGURE 13. DIRT II TRIAL A11 PASQUILL CATEGORY.  
Variation over Pasquill Stability Categories.

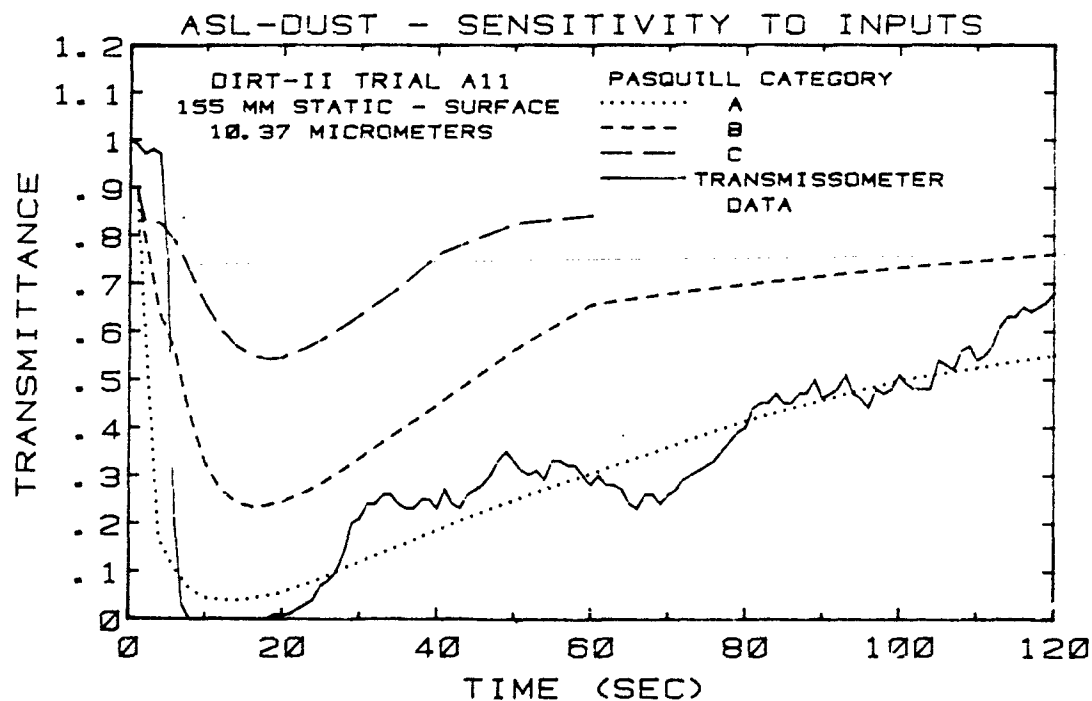


FIGURE 14. DIRT II TRIAL A11 PASQUILL CATEGORY.  
Variation over Pasquill Stability Categories.

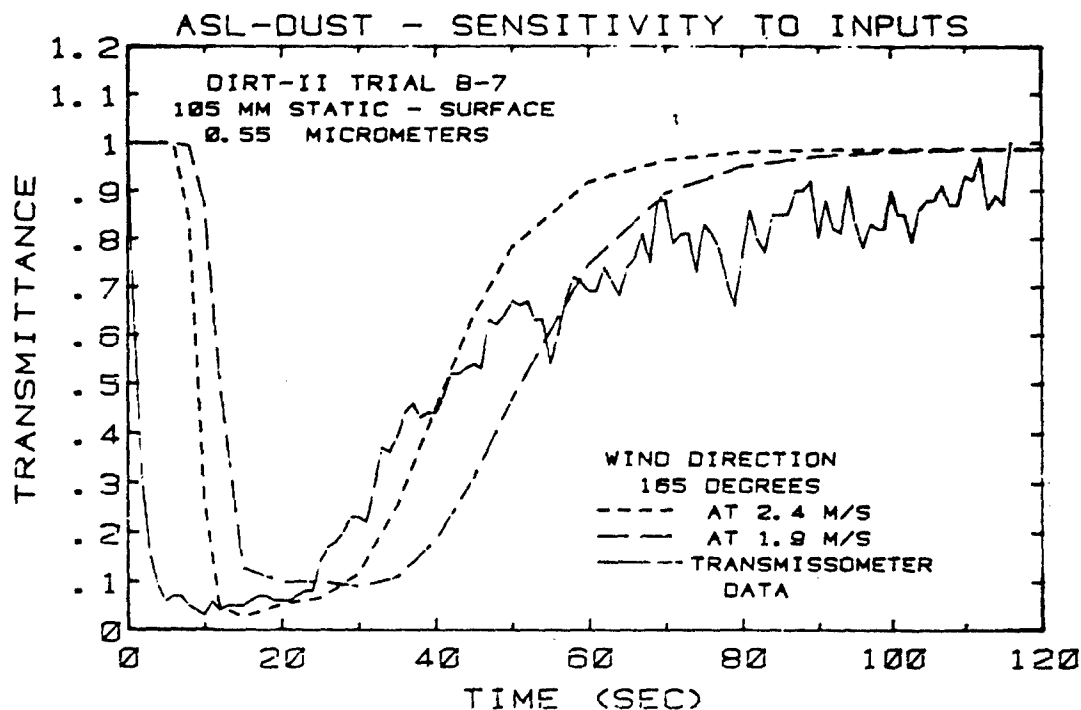


FIGURE 15. DIRT II TRIAL B-7 WINDS  
Variation in wind speed with constant direction.

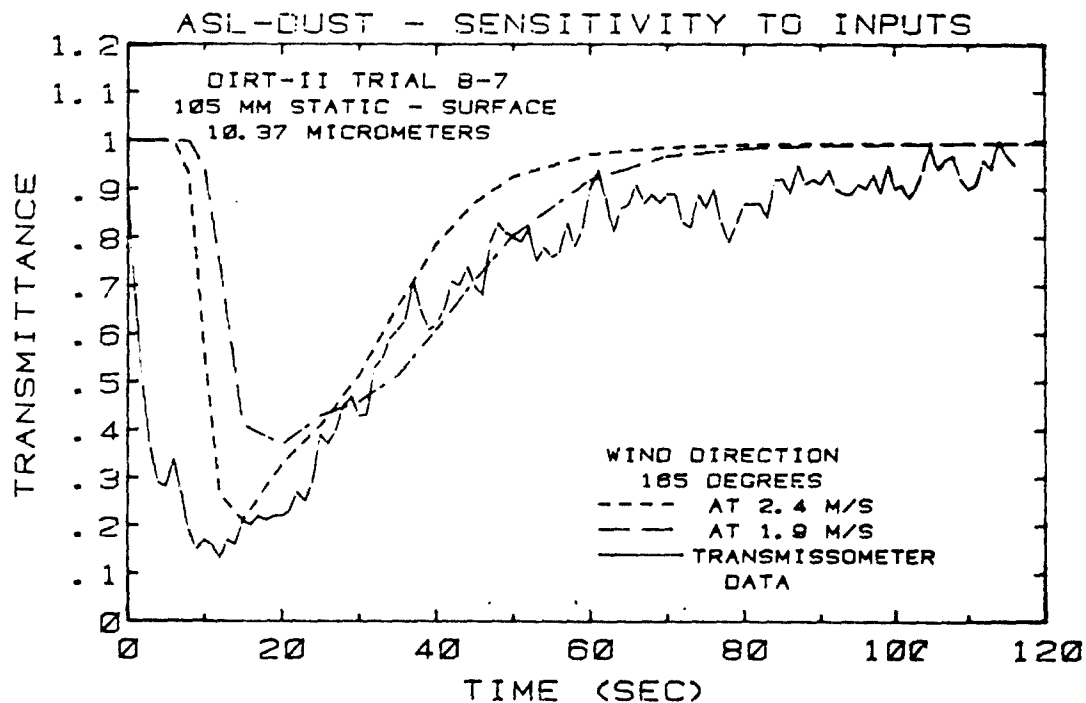


FIGURE 16. DIRT II TRIAL B-7 WINDS  
Variation in wind speed with constant direction.

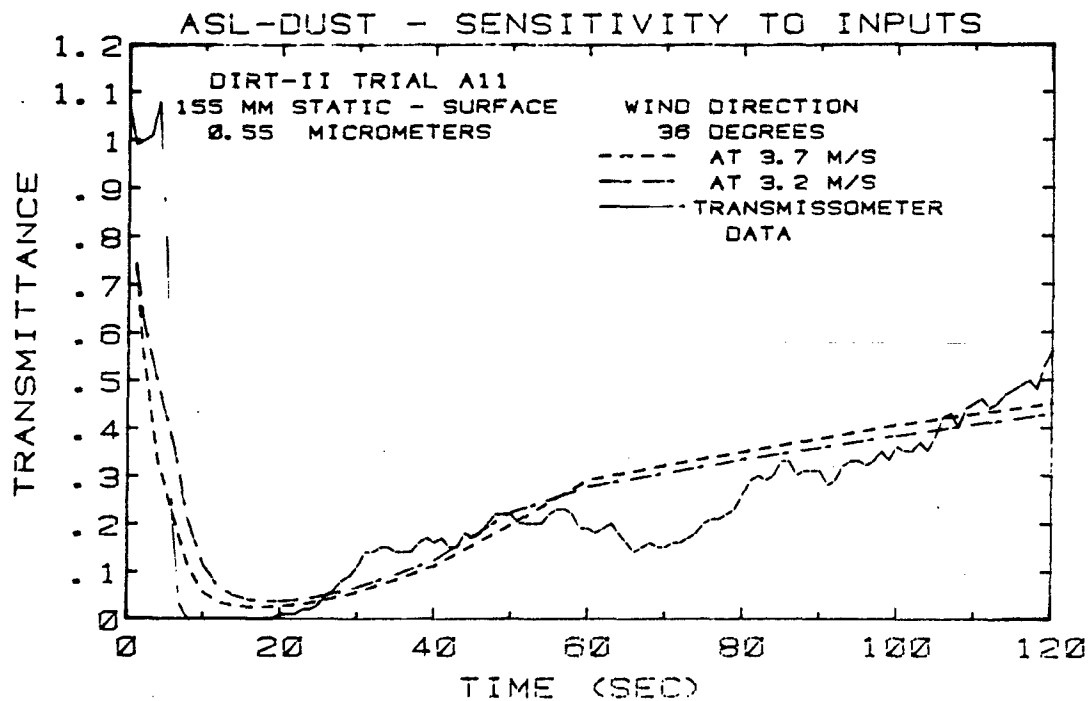


FIGURE 17. DIRT II TRIAL A11 WINDS  
Variation in wind speed with constant direction.

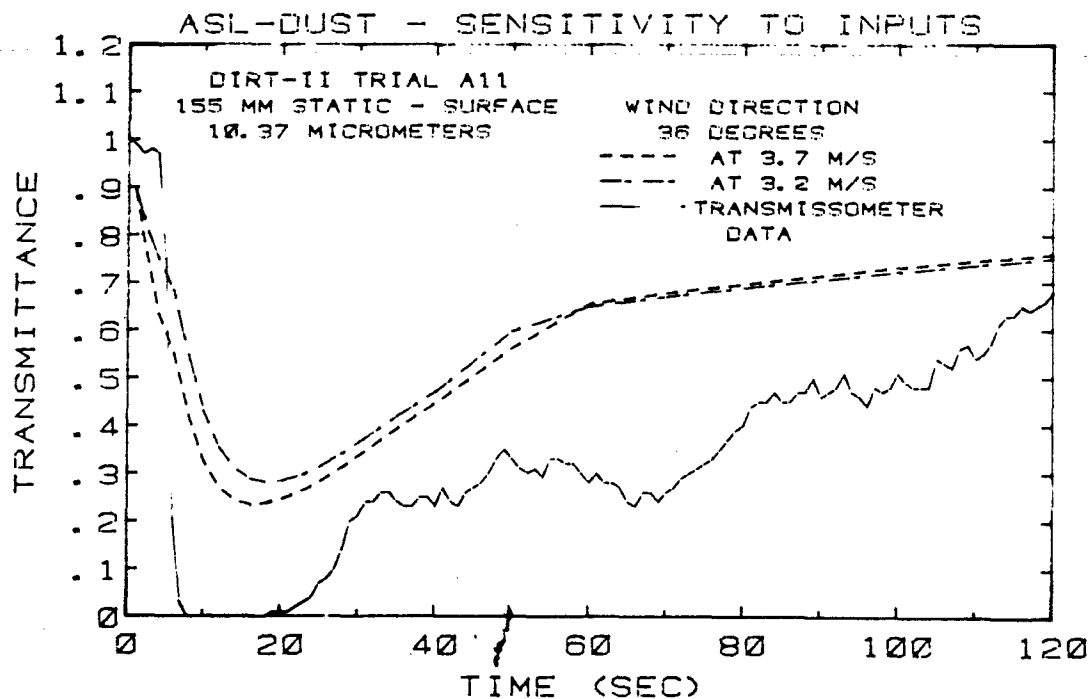


FIGURE 18. DIRT II TRIAL A11 WINDS  
Variation in wind speed with constant direction.

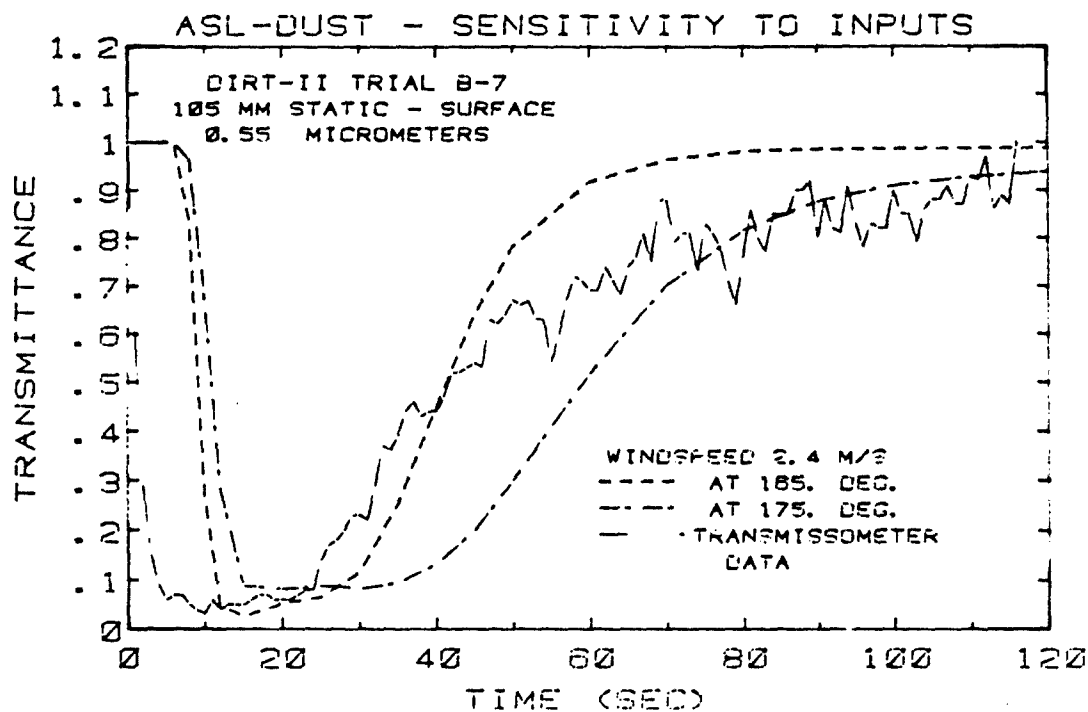


FIGURE 19. DIRT II TRIAL B-7 WIND DIRECTION  
Variation in wind direction at constant windspeed

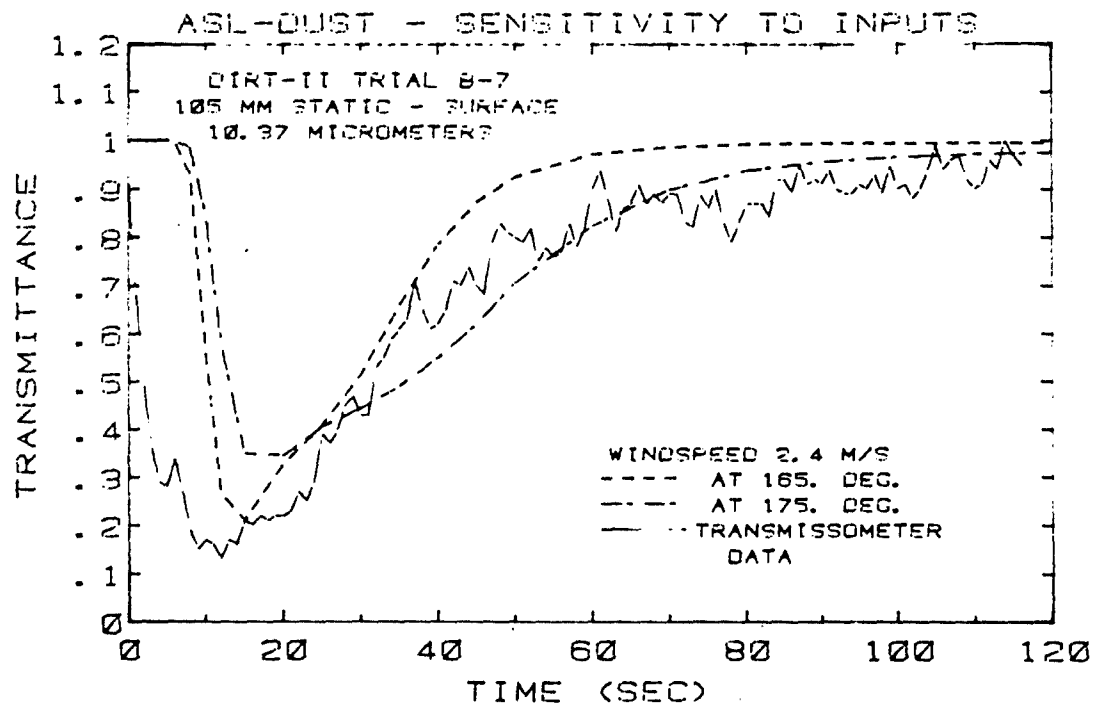


FIGURE 20. DIRT II TRIAL B-7 WIND DIRECTION  
Variation in wind direction at constant windspeed

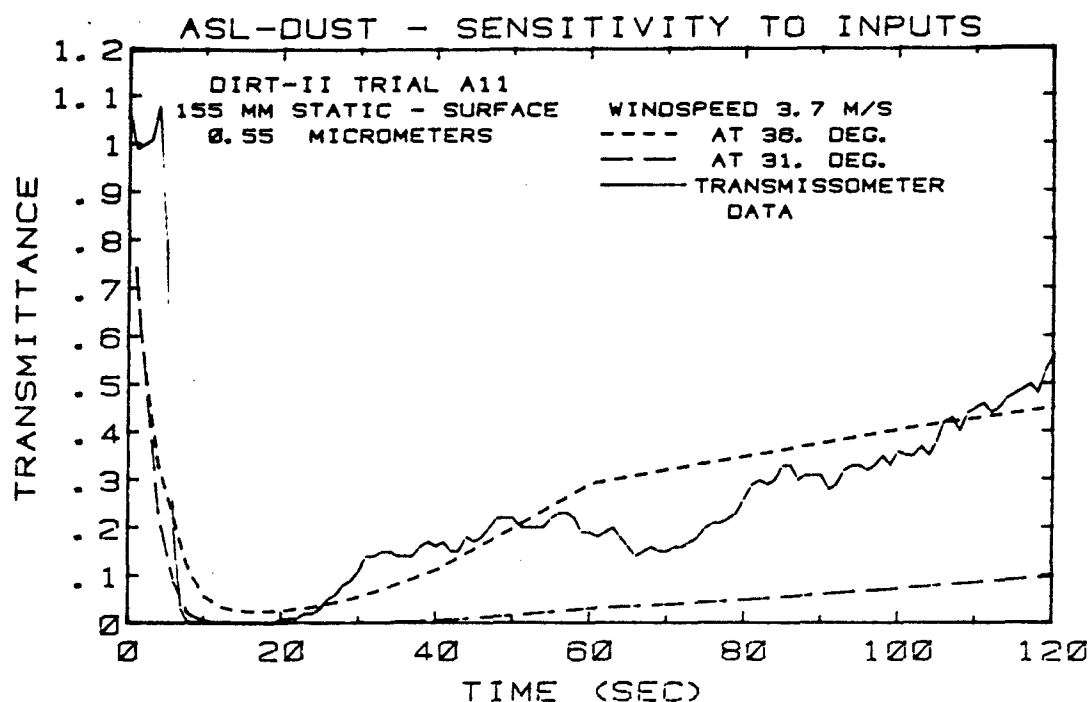


FIGURE 21. DIRT II TRIAL A11 WIND DIRECTION. Variation in wind direction with constant speed.

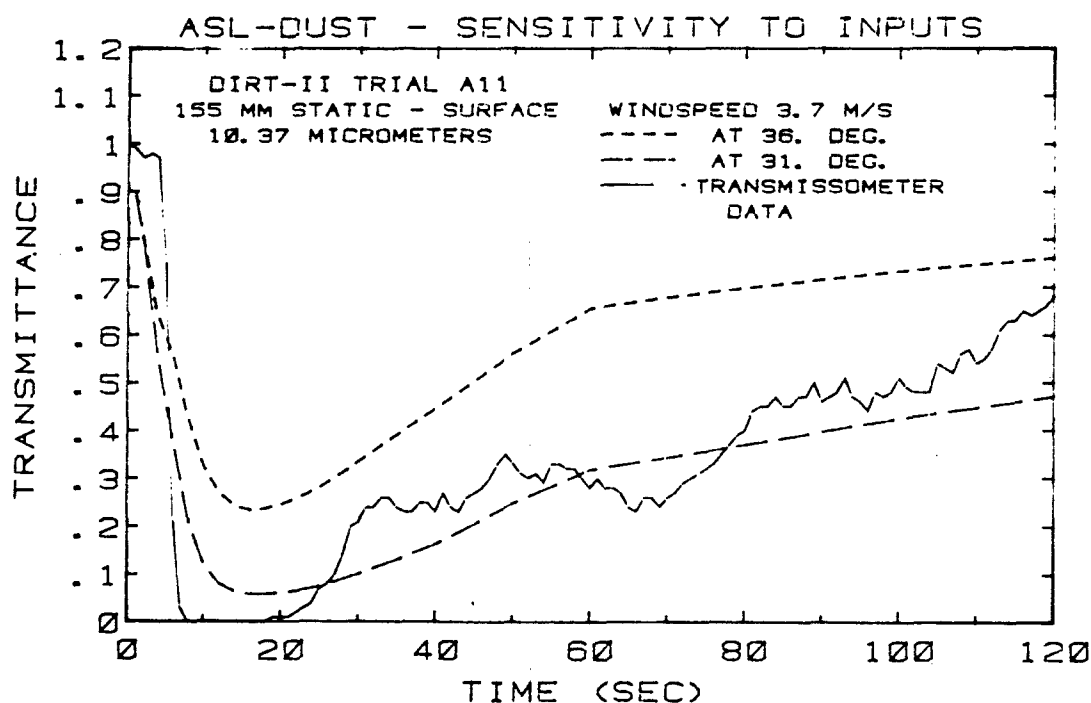


FIGURE 22. DIRT II TRIAL A11 WIND DIRECTION. Variation in wind direction with constant speed.

Figures 23 and 26 show the changes in simulated transmittance for a change in soil composition, and hence particle size distribution. The best initial estimate for the soils of the DIRT-II series was a composition of 25 percent clay, 50 percent silt, and 25 percent sand. To define a soil with a particle size distribution weighted toward larger sizes, a composition of 8 percent clay, 12 percent silt, and 80 percent sand was selected. Figures 23 through 26 show generally higher simulated transmittances for this second soil composition. This difference is to be expected because the larger sizes tend to give an overall smaller cross section to mass ratio. Also the ratio of visible to infrared transmittances is larger for the second soil composition. Again this is to be expected because the smaller proportion of clay-sized particles (mean diameter  $0.5\mu\text{m}$ ) causes relatively less extinction in the visible range.

#### 4. DISCUSSION AND CONCLUSIONS

The first phase of dust cloud modeling governs the cratering and initial cloud properties. The largest uncertainty lies in the correct determination of the actual amount of crater material which is lofted and remains airborne. Of secondary importance are the shape and size of the initial buoyant cloud and nonbuoyant dust skirt. Using the  $L_{cm}$  as the variable, comparisons with test data showed that the larger values of  $L_{cm}$  gave the better fits mainly because a cased artillery shell gives a larger crater than an equivalent bare charge for a given placement and soil type.

The second phase of dust cloud modeling deals with transport and diffusion. Four parameters were varied here. The first, the explosive energy partitioned to the initial cloud,  $E_p$ , influences the initial size of the main cloud, and hence the base cloud which is scaled to the main cloud, and the rise and expansion of the main cloud during its buoyant period. Increasing  $E_p$  tends to reduce the calculated transmittance during the early recovery phase because the larger base cloud and more rapidly expanding main cloud usually place more mass into the transmissometer line of sight. The second parameter  $P_s$ , the Pasquill category, is a quantification of atmospheric stability. Allowing the Pasquill parameter to assume higher values, that is, to represent a more unstable or turbulent atmosphere, is similar in its effect to increasing the previous parameter  $E_p$ . Higher values of  $P_s$  tend to cause lower simulated values of transmittance because more of the cloud is able to diffuse into the line of sight.  $P_s$  is varied in discrete steps, while nature varies in a continuous manner; therefore, a certain amount of care should be taken in correctly estimating a value of  $P_s$  to be used for modeling. The third parameter, the windspeed, directly affects the transport of the cloud. But its variation within a reasonable range was shown to have a small effect, particularly when the cloud's path was more or less parallel to the line of sight. The fourth parameter, the wind direction, also affects the transport of the cloud. However, small variations of the wind direction were found to produce large changes in simulated transmittances, in this case particularly when the cloud path was along the line of sight. Therefore, of the four parameters in the transport and diffusion phase of dust cloud modeling,  $E_p$  and

$P_s$  were found to have similar effects, the windspeed was found to be of lesser importance, and the wind direction was of major importance.

The third phase of dust cloud modeling deals with transmission through the cloud. The important quantities here are the particle size distribution and the indices of refraction. The particle size was chosen as the parameter to be varied. The best approach has been to divide the soil up into component parts, such as sand, silt, and clay, which can be determined from soil analysis, and then assign a particle size distribution and set of refractive indices to each component. These sets of size distributions are then taken to be present in the initial cloud in the same proportion as in the soil. The variation of the soil components can then change the relative transmittances of visible and infrared wavelengths.

Thus, all three phases of modeling of dust clouds from artillery explosions are sensitive to model parameters which cannot always be specified with high precision. The magnitudes of the changes in transmission produced by reasonable changes or uncertainties are comparable in several of these model parameters. Areas have been identified in which further model development is necessary. These areas include the early dynamic phase of base cloud and main cloud formation, variations in meteorological parameters over the time scale considered along with the large-scale turbulence, and the time dependent particle size distribution within the cloud.

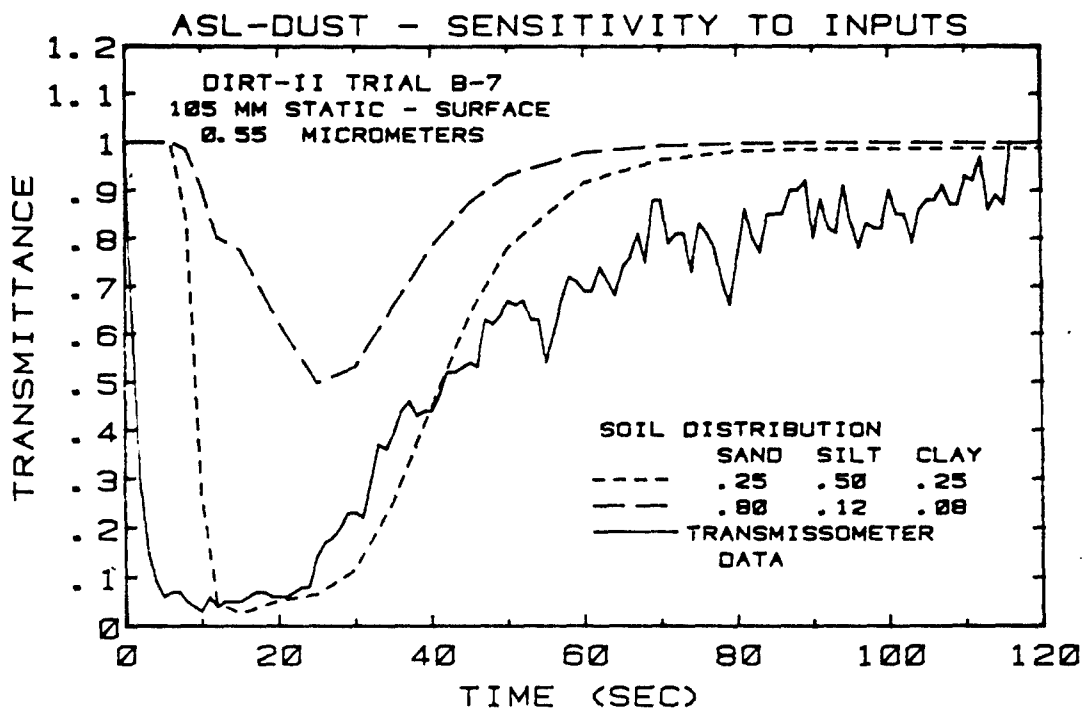


FIGURE 23. DIRT II TRIAL B-7 SOIL DISTRIBUTION  
Variation of percentage sand, silt and clay.

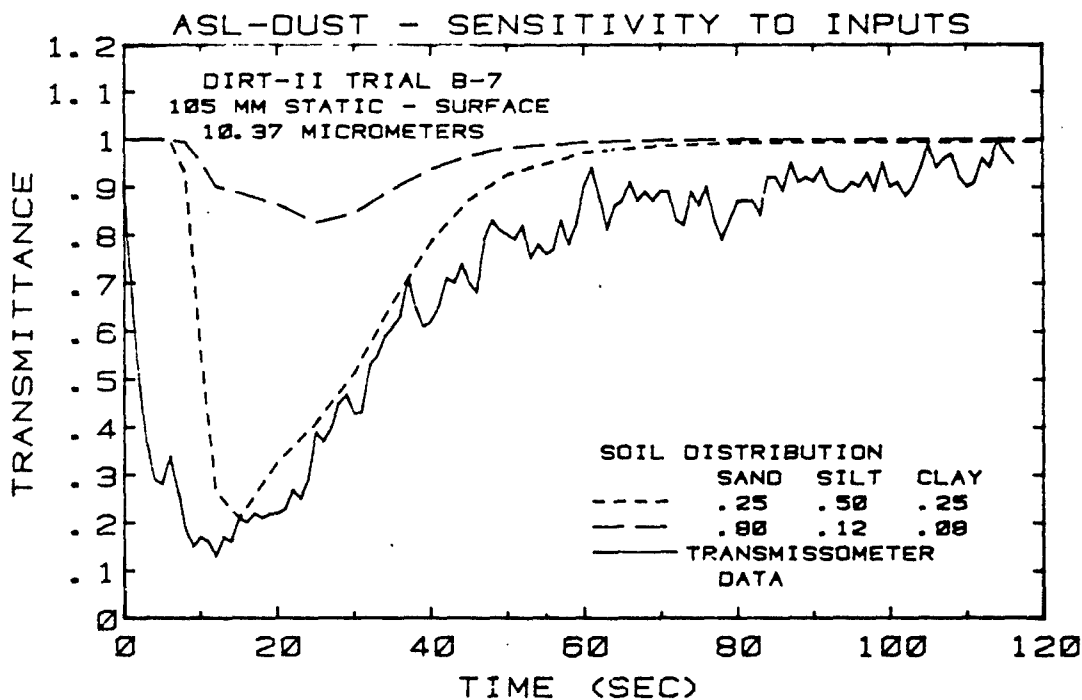


FIGURE 24. DIRT II TRIAL B-7 SOIL DISTRIBUTION  
Variation of percentage sand, silt and clay.

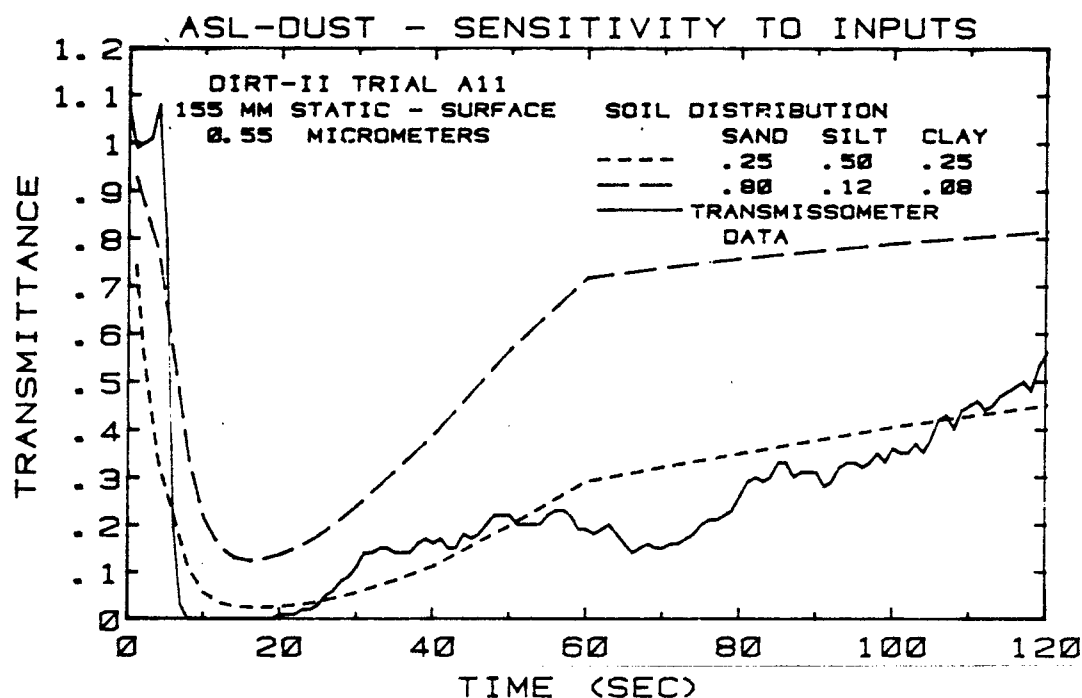


FIGURE 25. DIRT II TRIAL A11 SOIL DISTRIBUTION  
Variation of percentage sand, silt and clay.

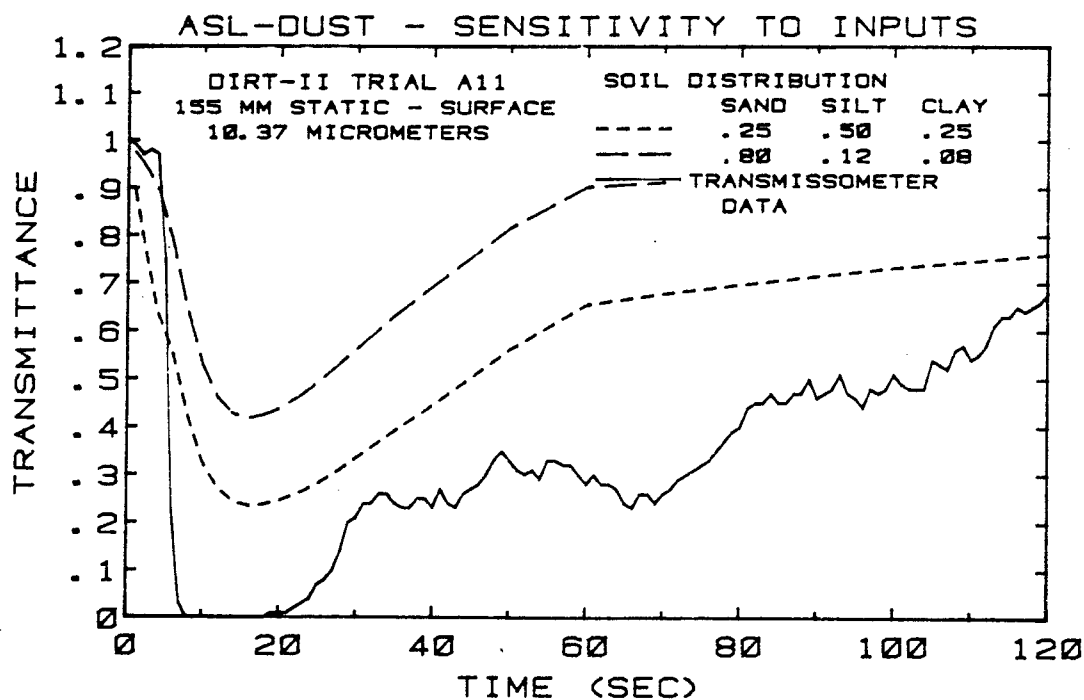


FIGURE 26. DIRT II TRIAL A11 SOIL DISTRIBUTION  
Variation of percentage sand, silt and clay.

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